Scientific Report

concerning the implementation of the project

Data Assimilation Methods for improving the WAVE predictions in the Romanian nearshore of the Black Sea - DAMWAVE

in the period January – December 2015

In the third stage of the project implementation carried out in the period above mentioned, the specific objectives of the project were pursued:

1. Validation of the results by applying the DA methodology for hindcast, for the extended period 2009-2013
2. Implementation of the wave prediction system, based on the SWAN model, with multi computational levels
3. Assessment of other DA procedures
4. Testing complex DA procedures that are associated with the wave prediction system in the Black Sea, focused on the Romanian nearshore
5. Results dissemination

1. Validation of the results by applying the DA methodology for hindcast, for the extended period 2009-2013

Additional hindcast simulations were carried out for a period of five years (2009-2013), that include all types of activities needed for new simulations specified in previous reports. Although in the initial project plan, it was previewed an extension of the model system simulation for a 2-year period (2009-2010), the experience accumulated and also the fact that satellite and wind data were allowed the simulation interval to be extended with an additional period of three years. In this way it was achieved a more consistent data base (closer to the present day) containing the results of the numerical simulations for the wave parameters in the Black Sea basin corresponding to a 15-year time interval (1999-2013), as also reliable information concerning the wind fields in the Black Sea. From this perspective, the climatology analysis was also updated.

Considering DA (Data Assimilation) scheme based on the optimal interpolation method implemented in the entire basin of the Black Sea in the second stage, the simulation results for the period 2009-2013 were also corrected. Also, for the entire period (1999-2013) the process of assimilation has been completed by propagating the information in the spectral space and the model was run with the initial conditions updated daily (Rusu, 2015a). Since the amount of data assimilated represents an essential issue in improving the quality of the assimilation results, some information on the number of the existing observations in the period under consideration are provided in Table 1. In the case of each altimeter, the period in which observations are available in the 15-year interval was also specified.

The statistical parameters considered to analyze the influence of the DA scheme on the quality of the H_s predictions are: mean measured and simulated values of the significant wave height, bias, mean absolute error, RMS error, scatter index (*SI*), correlation coefficient (*R*), and the regression slope (*S*), all of them being computed according to their standard definitions. First, the statistical parameters corresponding to the comparison between the H_s simulated by SWAN (Hs-SWAN) and the altimeter measurements considered for validation (ENVISAT, Topex, and Cryosat-2) were calculated. These statistical results are considered as a reference to evaluate the influence of the DA scheme on the quality of the wave predictions and they are presented in Table 2 (where *N* represents the number of pairs of data used in the statistical calculations). The statistical results obtained after applying the DA are also presented in Table 2. In the table, there are also presented the statistical results obtained after the application of DA for the correlation length of 4°. The analysis of the results presented in Table 2 clearly show that by applying the DA scheme the statistical parameters are improved. Scatter diagrams have been also designed and they are presented in Figure 1.

Table 1. The number of existing satellite observations in the 15-year time interval under consideration, structured in the number of observations used for assimilation and for validation, respectively.

Satellite	No. observations for assimilation	No. observations for validation
ERS-2 (until 04-07-2011)	197,136	
ENVISAT (14-05-2002 to 08-04-2012)		126,736
TOPEX (until 08-10-2005)		132,615
Poseidon (until 08-10-2005)	3821	
JASON-1 (15-01-2002 to 21-06-2013)	193,849	
GFO GFO (07-01-2000 to 07-09-2008)	101,693	
JASON-2 (from 04-07-2008)	102,038	
Cryosat-2 (from 14-03-2013)		57,569
SARAL (from 14-07-2010)	16,910	
Total	615,447	316,920

Table 2. Statistical results obtained for the *Hs* values simulated with SWAN and the *Hs* values obtained after the application of the DA method, against altimeter measurements used for validation across the Black Sea, results, corresponding to the time interval 1999–2013.

Parameter	MeanObs (m)	MeanSim (m)	Bias (m)	MAE (m)	RMSE (m)	SI	R	S	N
SWAN H_s(m)	1.04	0.97	−0.07	0.27	0.35	0.35	0.88	0.98	316920
SWAN-DA H_s (m)		1.01	−0.03	0.21	0.29	0.28	0.91	0.99	

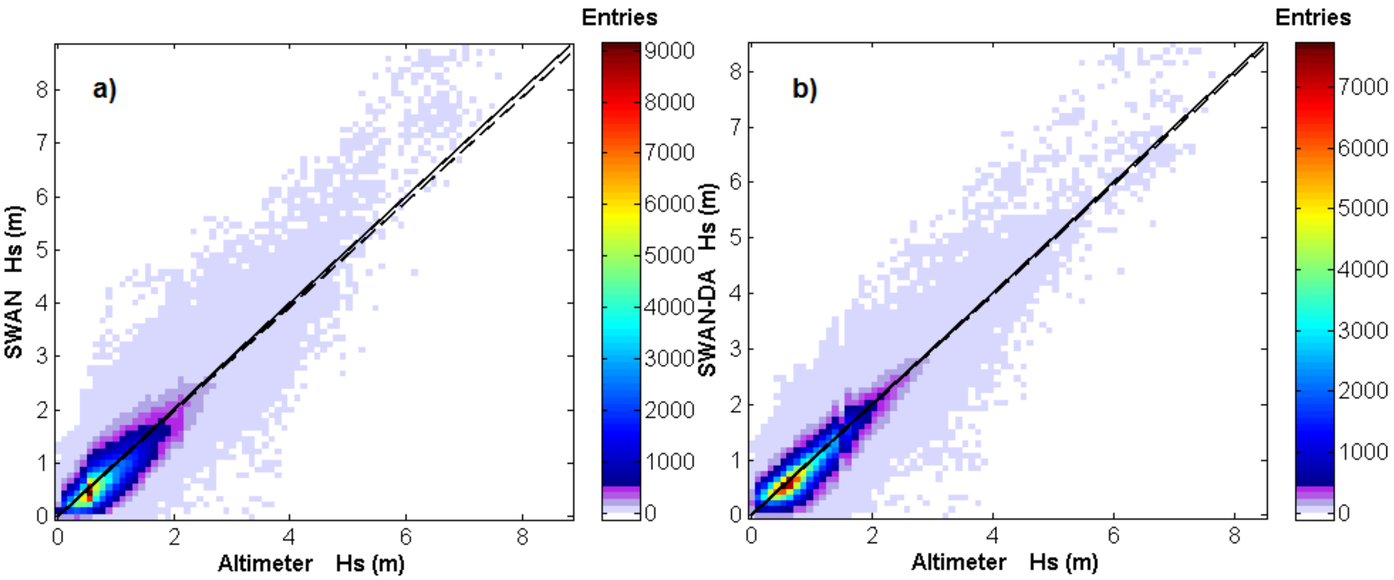

Figure 3. Scatter diagrams presenting the observed *Hs* (data from ENVISAT, Topex and Cryosat-2 satellites) against the predicted *Hs* computed using the SWAN model without DA (**a**) and with DA (**b**), corresponding to the 15-year period (1999–2013). The different colors indicate different quantities of data in the single pixels. The solid lines denote the perfect fit to the modelled and observed values and the dashed lines represent the best-fit slope.

From this perspective, taking into account that a detailed knowledge of the environmental conditions in this marine environment represents an issue of high and increasing importance, the results of a 15-year wave hindcast in the Black Sea, covering the time interval 1998–2013 were analyzed focused on the storm conditions. According to these data, the western side of the sea appears to be slightly more energetic than the rest. The storms can become quite strong and they can generate marine and coastal hazards. Thus, each year we can expect somewhere in the

Black Sea significant wave heights around 8 meters, which means that the corresponding maximum wave heights can exceed 15 meters. While such conditions can be considered characteristic for the regular strong storms, the extreme events (that may occur once in 10–15 years) can produce waves even greater that 20 meters (with significant wave heights greater than 10 meters).

The simulation results were used for various analyses concerning the environmental conditions in the Black Sea, as the evaluation of the extreme conditions (Rusu & Butunoiu, 2015) or wave energy assessments (Rusu, 2015a,b). In this respect, Figures 2 and 3 present some geographical distributions related to the wave energy.

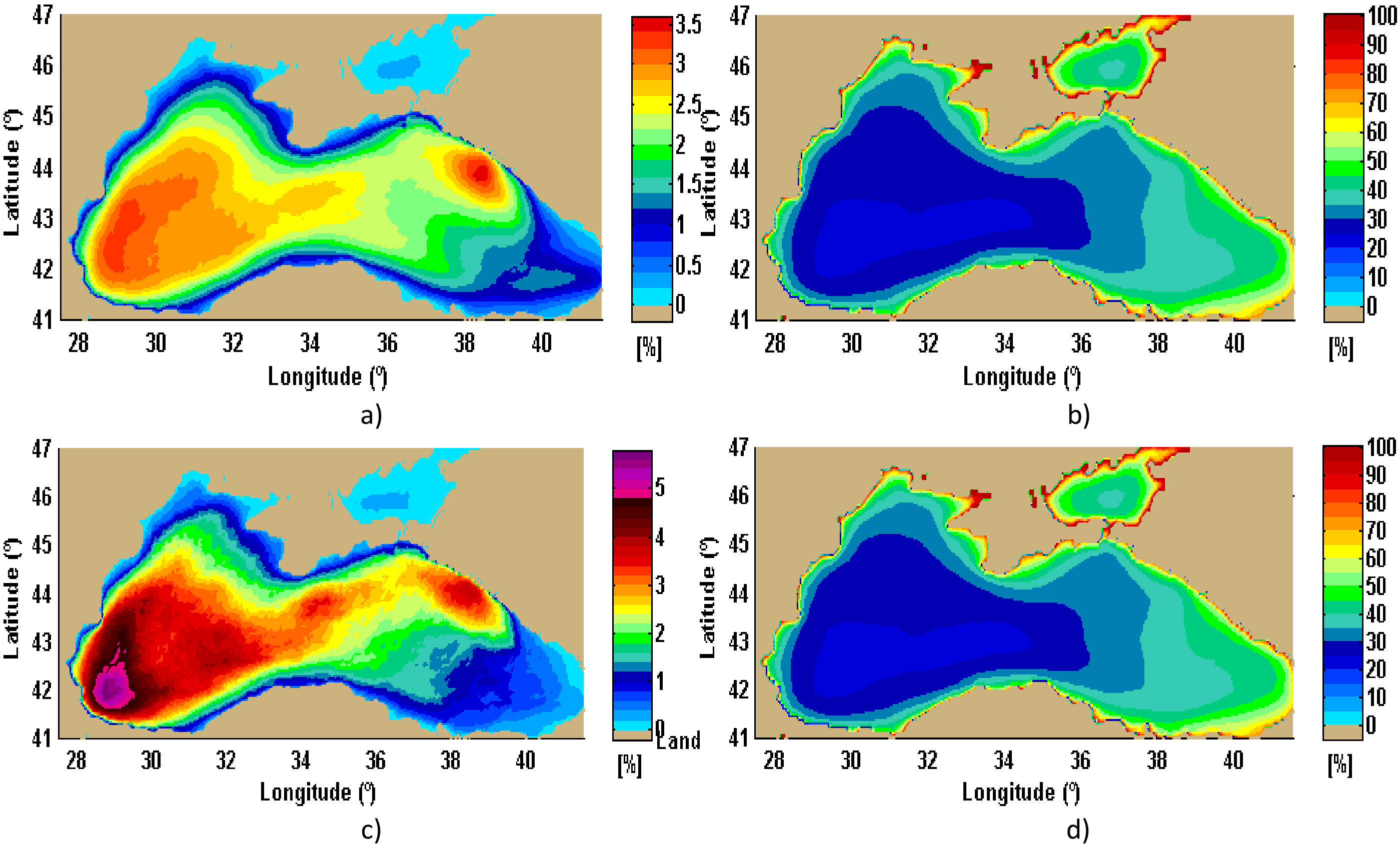

Figure 2. Results of the 15-year wave simulations (1998–2013); a) Geographical distribution of the storm conditions in percentage (significant wave heights greater than 3 m); b) Geographical distribution of the calm conditions in percentage (significant wave heights lower than than 0.5 m); Year 2003 (c) and year 2013 (d), geographical distribution of the storm conditions in percentage (significant wave heights greater than 3 m).

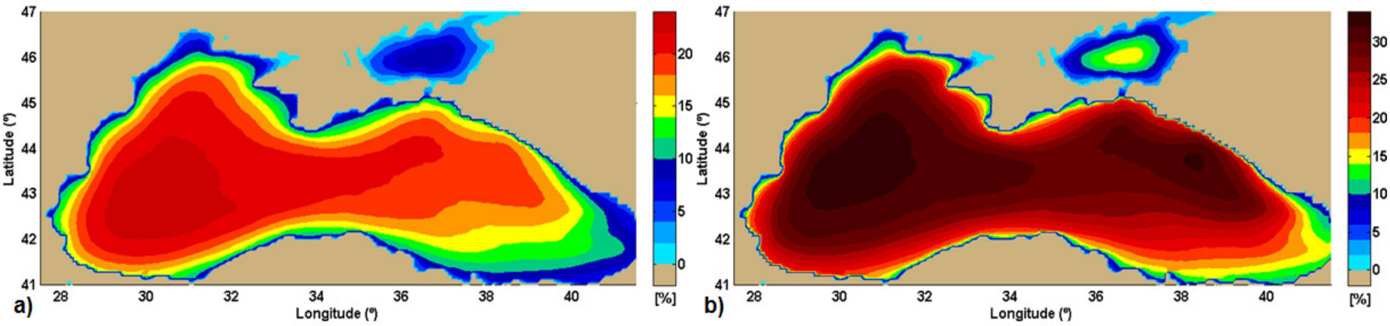

Figure 3. Results of the 15-year wave simulations (1998–2013); (**a**) Geographical distribution in percentage of the wave power greater than 4 kW/m, total period; (**b**) Geographical distribution in percentage of the wave power greater than 4 kW/m, winter period.

2. Implementation of the wave prediction system, based on the SWAN model, with multi computational levels

A three-level wave prediction system was considered for the Romanian nearshore and is presented in Figure 4:

Level I - Global, represents the generation area and cover the entire Black Sea basin; **Level II - Coastal** is the transformation area and cover the Romanian coastal environment and **Level III – Local**, represents the highest resolution areas. The wind field considered for forcing the wave model was that provided by NCEP-CFSR (United States National Centers for Environmental Prediction, Climate Forecast System Reanalysis) with a spatial resolution of 0.312º×0.312º and a temporal resolution of 3 h. The characteristics of the three computational grids are presented in Table 3.

Table 3. The computational grids considered in the two-level SWAN based modelling system

Level	Δx × Δy	Δt (min) / computational mode	nf	nθ	ngx × ngy = np
Global I	0,08° × 0,08°	10 / non-stat	35	24	176 × 76 = 13376
Coastal II	0,02° × 0,02°	10 / non-stat	35	36	141 × 141 = 19881
Local III	0,005° × 0,005°	10 / non-stat	35	36	221 × 221 = 48841

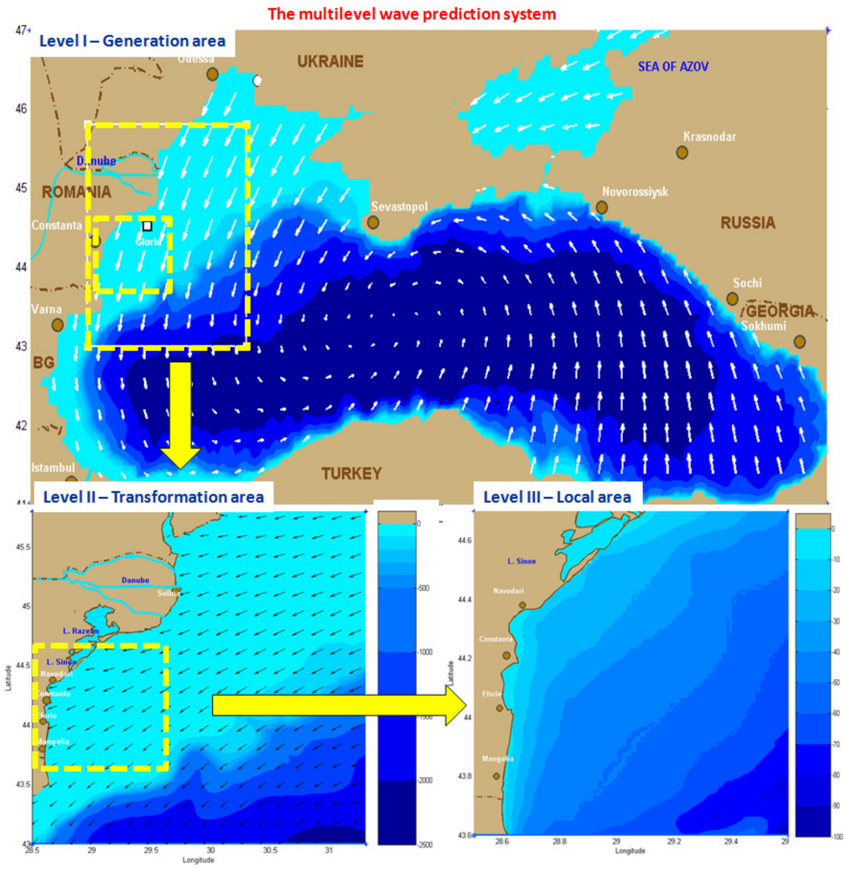

Figure 4. The geographical spaces of the wave prediction system considered in the Black Sea: a) Level I - area of generation, b) Level II – coastal transformation domain. In the background the bathymetric maps of the areas are represented while in the foreground the wind vectors corresponding to the conditions from 2002/02/04/h18 (white arrows).

The main physical processes were considered for each computational level (generation by wind, whitecapping, quadruplet nonlinear wave-wave interactions, bottom friction and wave breaking), although some parameterizations were different. The validation of the results obtained at the Level II of the wave prediction system was made by comparison between simulation results and satellite measurements (Figure 5), Răileanu et al. (2015).

There have been accomplished various tests concerning the impact of different physical processes on the wave modelling in the transformation area. From this perspective, we have noticed that in this area, it appears as most reliable in SWAN Westhuysen parameterization for whitecapping (Van der Westhuysen et al., 2007), while in the generation area the best results are provided by the physical parameterization proposed by Janssen (1991). Figure 6 presents the results provided by the SWAN simulations corresponding to Level II for two different time frames corresponding to average and extreme situations, respectively and presenting the significant wave height scalar fields.

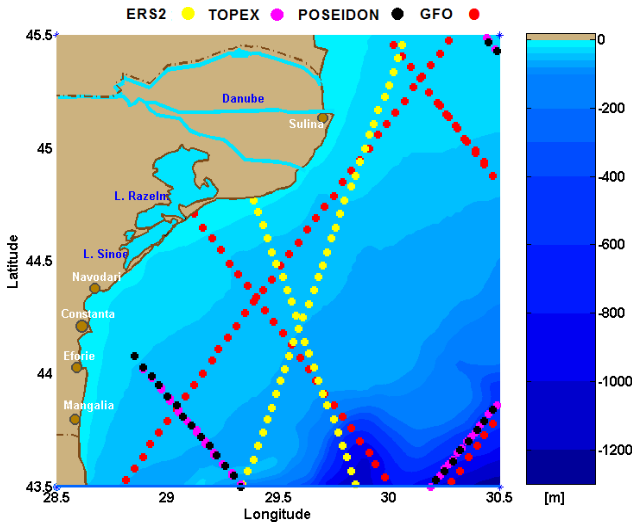

Figure 5. January 2001, the satellite tracks over the Romanian coastal area (Level II).

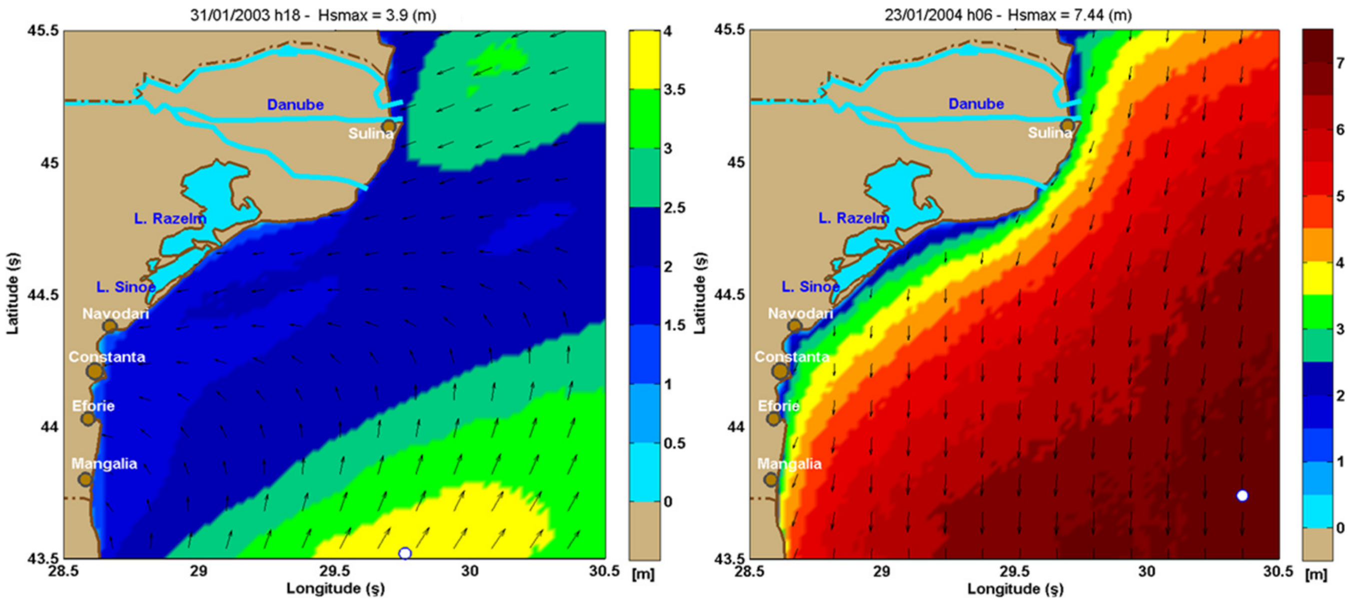

Figure 6. Significant wave height scalar fields and wave vectors simulated with SWAN model, time frames 31/01/2003 h18 and 23/01/2004 h06.

At the same time, the wave prediction system was also focused on various local areas considering high resolution computational domains in the geographical space (Level IV), in which the Cartesian coordinate system was considered in defining the computational grids. In such areas were also analyzed the particular conditions that may be relevant in the wave modelling process, as for example the wave-current interactions. An example is represented by the study performed in the coastal area of the Sacalin Island (Rusu & Butunoiu, 2015), where the most relevant wave propagation patterns were analyzed together with the coastal circulation patterns induced by the Danube River outflow (Saint George arm).

Model system simulations have been performed considering the most relevant wave propagation patterns specific to this coastal environment. A first conclusion would be that the results provided by the modeling system developed herewith are in general in line with the outputs of the previous studies based mainly on observations and some in situ measurements and these model results directly help in both following and explaining the very dynamic coastal evolutions in the target area. Thus, the model results reveal two antagonist processes. The first, which is dominant, and that can be defined as a constructive process, corresponds to the most common wave propagation pattern in the target area (that is the waves coming from the northeast). In this case, the alluvial river input, combined with the longshore sediment transport, determines the southern extension of the Sacalin Island. In fact, this was also the mechanism that determined the generation of the Sacalin Island more than one century ago.

3. Assessment of other DA procedures

Since the objective of the project is to improve the wave predictions in the western side of the Black Sea, mainly in the Romanian nearshore, the assimilation procedure was applied only to the second computational level, which was denoted in Figure 4 as the transformation area. Following the DA methodologies widely applied to perform wave predictions on various geographical areas (Răileanu & Rusu, 2015), and after analyzing the advantages and the disadvantages of each approach, an algorithm based on the Succesive Correction Method has been considered and implemented for the entire computational level that comprises the western side of the basin. The assimilation technique considered assumes linear regressions to perform corrections to the model predictions in order to fit better the observations. A similar approach was applied successfully by Rusu (2014) for the assimilation of both the significant wave height and the mean wave period at the location of the Gloria platform.

Thus, the data assimilation scheme adopted is based on a successive correction algorithm. For every day *d*, the predictions produced for 00h to 21h with a 3 hour resolution in each point of the computational grid are corrected in terms of significant wave height in relationship with the satellite measurement. Using the ensemble of the measurements and the corresponding predictions produced in the previous **d-n** days (denoted as the training period), the goal was to find the parameter values for a linear regression which best fits the data set. These parameters were then used to correct the predictions produced at day *d*, which represents the assimilation period. The regression parameters are estimated by using the Ordinary Least-Square method.

In Table 4 there are presented the statistical results computed after the comparisons against the satellite data for the *Hs* simulated with SWAN and that resulted after applying the DA technique. It can be noticed very easily that the results are improved for all statistical parameters after DA application.

Table 4. Statistical results obtained for *Hs* simulated with SWAN and *Hs* with DA, against satellite data, time period 1999-2008.

Parameter	MeanObs (m)	MeanSim (m)	*Bias* (m)	*MAE* (m)	*RMSE* (m)	*SI*	*R*	*S*	*N*
Hs (without DA)	1.053	1.041	-0.012	0.241	0.325	0.309	0.894	1.007	40,759
Hs (with DA)	1.053	1.052	-0.001	0.206	0.273	0.259	0.917	0.974	

Figure 7 presents the results after applying the DA scheme corresponding to the entire computational domain and for the same time frames as the cases presented in Figure 6. Thus, by comparing the results illustrated in Figures 6 and 7, corresponding to exactly the same moment we can notice more clear the impact in the model predictions of the data assimilation.

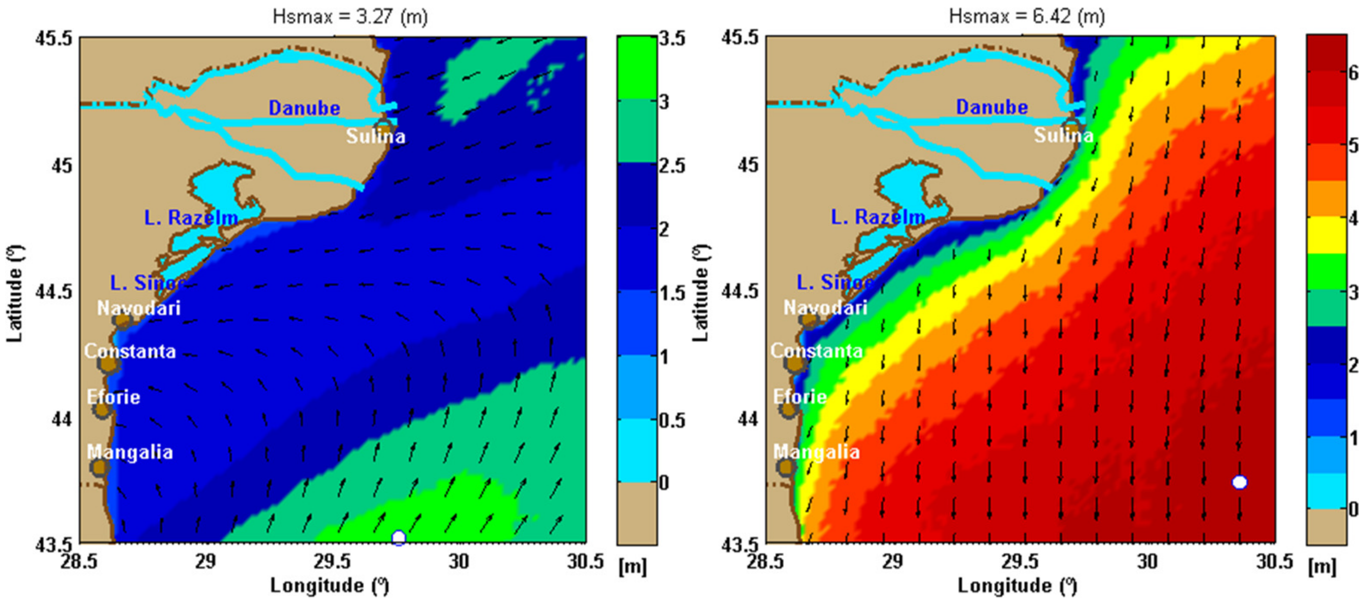

Figure 7. Significant wave height scalar fields (H_s) and mean wave direction after applying the DA scheme, corresponding to the time frames 31/01/2003 h18 (left) and 23/01/2004 h06 (right).

Besides the DA methods implemented until now, and for which the results were disseminated, the members of the project team are currently working to implement and test a DA procedure based on the Kalman filter. After assessing the final results, an opportunity analysis will be also performed in order to identify the effectiveness of each DA approach. In order to establish which would be the most reliable approach, the accuracy of the results corresponding to each methodology will be evaluated in conjunction with the computer time required for applying the methodology.

4. Testing complex DA procedures that are associated with the wave prediction system in the Black Sea, focused on the Romanian nearshore

The results obtained after the application of the DA scheme for the second computational level (Level II) are considered also implementation of some other DA techniques, in which the boundary conditions at the third computational level are modified, establishing in this way in a more complex scheme that covers all the computational levels of the wave prediction system. The in situ measurements performed at the Gloria drilling unit will be considered also for assimilation.

In this respect, it was already accomplished a multilevel DA scheme that might be adapted for assimilation of more wave parameters (significant wave height, wave period, wave direction and directional spreading of waves). At the same time it was considered the possibility to adapt easily this scheme from hindcast studies to nowcast and operational wave forecast. These above mentioned results are presented in a scientific work that was submitted to the Journal of Operational Oceanography, and which is currently under evaluation.

5. Dissemination of the results

5.1 Preparation of the scientific articles, a monograph, oral presentations and posters to disseminate the results

- Publications in international journals with ISI quotation (7)

1. Rusu, L., 2015. Assessment of the Wave Energy in the Black Sea based on a 15-Year Hindcast with Data Assimilation, *Energies* 8, 10370-10388. http://dx.doi.org/10.3390/en80910370 (IF=2.072)
2. Rusu, L., Onea, F., 2015. Assessment of the performances of various wave energy converters along the European continental coasts, *Energy* 82, 889-904. http://dx.doi.org/10.1016/j.energy.2015.01.099 (IF=4.844)
3. Rusu, L., Butunoiu, D., 2015. Numerical modelling of the wave propagation close to the sacalin island in the Black Sea, *Journal of Marine Science and Technology* - Taiwan, 23(5), 669-677. DOI:10.6119/JMST-015-0521-2 http://jmst.ntou.edu.tw/marine/23-5/669-677.pdf (IF=0.379)
4. Onea, F., Raileanu, A., Rusu, E., 2015. Evaluation of the Wind Energy Potential in the Coastal Environment of two Enclosed Seas, *Advances in Meteorology*, Article ID 808617. http://dx.doi.org/10.1155/2015/808617 (IF=0.946)
5. Omer, I., Mateescu, R., Rusu, L., Niculescu, D., Vlasceanu, E., 2015, Coastal works extensions on the Romanian touristic littoral, its ecological impacts on the nearshore bathing areas, *Journal of Environmental Protection and Ecology* 16 (2), 424-433. http://www.jepe-journal.info/vol-16-no2-2015 (IF=0.838)
6. Onea, F., Rusu, E., Efficiency assessments for some state of the art wind turbines in the coastal environments of the Black and the Caspian seas, *Energy Exploration & Exploitation* - accepted October2015, http://hebeu.allmaga.net/eee/ch/first_menu.aspx?parent_id=20101109165126001 (IF=0.778)
7. Rusu, E., Onea, F., 2016. Estimation of the wave energy conversion efficiency in the Atlantic Ocean close to the European islands, *Renewable Energy* 85, 687-703. http://dx.doi.org/10.1016/j.renene.2015.07.042 (IF= 3.476)

- Publications in the proceedings of international conferences (14)

8. Rusu, L., 2015. Wave modelling with data assimilation to evaluate the wave energy patterns in the Black Sea. In: *Proc. of 15th International Multidisciplinary Scientific GeoConference* (SGEM2015), 16-25 June, Albena, Bulgaria, Vol. 4, 597-606. http://www.sgem.org/SGEMLIB/spip.php?article6182 (ISI indexed) DOI:10.5593/SGEM2015/B41/S17.078

9. Butunoiu, D., Rusu, E., 2015. A Data Assimilation Scheme to Improve the Wave Predictions in the Black Sea. In: *Proc. of OCEAN'15 MTS/IEEE Conference - Discovering Sustainable Ocean Energy for a New World*, 18-21 May, Genova, Italy. http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7271242 (ISI indexed) DOI:10.1109/OCEANS-Genova.2015.7271242

10. Onea, F., Rusu, L., 2015. Coastal impact of a hybrid marine farm operating close to the Sardinia island. In: *Proc. of OCEAN'15 MTS/IEEE Conference - Discovering Sustainable Ocean Energy for a New World*, 18-21 May, Genova, Italy. http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7271249 (ISI indexed) DOI:10.1109/OCEANS-Genova.2015.7271249

11. Răileanu, A., Onea, F., Rusu, E., 2015. Assessment of the wind energy potential in the coastal environment of two enclosed seas. In: *Proc. of OCEAN'15 MTS/IEEE Conference - Discovering Sustainable Ocean Energy for a New World*, 18-21 May, Genova, Italy. DOI:10.1109/OCEANS-Genova.2015.7271248 http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7271248 (ISI indexed)

12. Răileanu, A., Onea, F., Rusu, E., Evaluation of the offshore wind resources in the European seas based on satellite measurements, In: *Proc. of 15th International Multidisciplinary Scientific GeoConference* (SGEM2015), 16-25 June, Albena, Bulgaria, Vol. 4, 227-234. DOI: 10.5593/SGEM2015/B41/S17.030 http://sgem.org/sgemlib/spip.php?article6134 (ISI indexed)

13. Răileanu, A., Rusu, L., Rusu, E., 2015. Wave modelling with data assimilation in the Romanian nearshore. In: Proc. of 16th International Congress of the International Maritime Association of the Mediterranean, IMAM 2015 - Towards Green Marine Technology and Transport, 21-24 September, Croatia, pp. 837-843, http://www.imamhomepage.org/imam2015/ (ISI indexed)

14. Rusu, E., Butunoiu, D., 2015. Prediction of the extreme storms in the Black Sea with numerical wave models, In: *Proc. of 16th International Congress of the International Maritime Association of the Mediterranean*, IMAM 2015 - Towards Green Marine Technology and Transport, 21-24 September, Croatia, pp. 845-851, http://www.imamhomepage.org/imam2015/(ISI indexed)

15. Rusu, L., Răileanu, A., 2015. Assimilation of satellite data to increase the reliability of the wave predictions in the Black Sea. Poster presented at *European Geosciences Union General Assembly 2015* (EGU2015), Geophysical Research Abstracts, Vol. 17, EGU2015-4816, 12-17 April, Vienna, Austria http://meetingorganizer.copernicus.org/EGU2015/posters/17327 http://meetingorganizer.copernicus.org/EGU2015/EGU2015-4816.pdf

16. Rusu, E., Butunoiu, D., 2015, Wave modelling south of the Danube Delta in the Black Sea, Poster presented at*European Geosciences Union General Assembly 2015* (EGU2015), Geophysical Research Abstracts, Vol. 17, EGU2015-4816, 12-17 April, Vienna, Austria.
http://meetingorganizer.copernicus.org/EGU2015/posters/17342
http://meetingorganizer.copernicus.org/EGU2015/EGU2015-4887.pdf

17. Rusu, L., Răileanu, A., Rusu, E., 2015. An assimilation scheme based on remotely sensed data to improve the results of the numerical wave models in the Black Sea, *International Conference Environmental Issues in terms of its Protection and Ecology*, 6-7 May 2015, Galaţi, Romania, pp 11-12, ISBN 978-606-696-035-9.

18. Onea, F., Răileanu, A., Rusu, E., 2015. Evaluation of the general wind conditions in the Black and the Caspian seas,*International Conference Environmental Issues in terms of its Protection and Ecology*, 6-7 May 2015, Galaţi, Romania, pp. 13-14, ISBN 978-606-696-035-9.

19. Rusu, L., Onea, F., 2015. Shoreline effects of a wind-wave farm operating in the coastal environment of the Mediteranean Sea, *International Conference Environmental Issues in terms of its Protection and Ecology*, 6-7 May 2015, Galaţi, Romania, pp. 15-16, ISBN 978-606-696-035-9.

20. Raileanu, A., Onea, F., Rusu, E., 2015. Evaluation of the offshore wind energy potential in the Romanian coastal environment at the Black Sea, presented at *The international symposium Protection of the Black Sea ecosystem and sustainable management of maritime activities - PROMARE 2015*, http://www.mareframe-fp7.org/ue_31.html, to be published in Cercetari Marine / Marines Reserches" vol. 45/2015. http://www.rmri.ro/Home/Publications.RecherchesMarines.html

21. Ivan, A., Raileanu, A., Onea, F., Rusu, E., 2015. Studies concerning the coastal impact of an offshore wind farm operating in the vicinity of the Danube Delta, presented at *The international symposium Protection of*

the Black Sea ecosystem and sustainable management of maritime activities - PROMARE 2015, http://www.mareframe-fp7.org/ue_31.html, to be published in Cercetari Marine / Marines Reserches" vol. 45/2015. http://www.rmri.ro/Home/Publications.RecherchesMarines.html

- Publications in national journals indexed in international databases (2)

22. Onea, F., Rusu, E., 2015. Analysis of some numerical simulations related to a hybrid wave energy converter, Annals of "Dunarea de Jos" University of Galati, Mathematics, Physics, Theoretical Mechanics, Fascicle II, Year V(XXXVIII) 2015, pp. 46-52. (B+) http://www.phys.ugal.ro/Annals_Fascicle_2/Year2015/Vol1.htm
23. Butunoiu, D., Rusu, E., 2015. Study of the waves transformation in the Romanian coastal environment, Annals of "Dunarea de Jos" University of Galati, Mathematics, Physics, Theoretical Mechanics, Fascicle II, Year V(XXXVIII) 2015, pp. 129-136. (B+) http://www.phys.ugal.ro/Annals_Fascicle_2/Year2015/Vol1.htm

- Publications in the proceedings of national conferences (2)

24. Onea, F., Rusu, E., 2015. Analysis of some numerical simulations related to a hybrid wave energy converter. Oral presentation at the Scientific Conference organised by the Doctoral Schools of "Dunarea de Jos" University of Galati (CSSD-UDJG 2015), 4-5 June, Galati, Romania. http://www.cssd-udjg.ugal.ro/index.php/abstracts
25. Raileanu, A., Rusu, E., 2015. Evaluation of Various Data Assimilation Procedures to Increase the Reliability of the Wave Predictions in the Black Sea, Oral presentation at the Scientific Conference organized by the Doctoral Schools of "Dunarea de Jos" University of Galati (CSSD-UDJG 2015), 4-5 June, Galati, Romania. http://www.cssd-udjg.ugal.ro/index.php/abstracts

- **Achievement in a percentage of about 80% of a monograph with the title** "*Data assimilation with applications to the prediction of the wave climate in the Black Sea basin"*, authors Liliana Rusu, Alina Răileanu and Florin Onea.

It is expected to finalize this monograph in the first part of 2016, in order to include also the final results concerning the implementation of the DA techniques in the Romanian nearshore.

5.2 Continuous updating of the project DAMWAVE site http://www.im.ugal.ro/DAMWAVE/index.htm

During the project unfolding the web page of the project was continuously updated with the activities and the results of the project.

5.3 Supporting young researchers

Collaboration and supervision of master and PhD students and postdoctoral researchers represents a continuing concern of the members of the research team, having as objective to develop studies directly related to the area of the project, but also with some related areas. It has to be mentioned also that Professor Eugen Rusu, member of the research team, was the supervisor of 4 master dissertations defended in 2015. The names of the master graduates and the topics are also to be found on the web page of the DAMWAVE project. Also, a PhD with the theme: *Implementation of data assimilation methods to improve the wave prediction in the basin of the Black Sea* (drd. eng. Alina Răileanu, member of the research team) is ongoing.

Thus, in the framework of the project an important number of works where young researchers are included have been published according to the list presented above.

6. Concluding remarks

In this final section, we can appreciate that all the proposed objectives for this stage have been reached integral. Additional simulations have been performed in order to extend the database concerning the wave predictions in the Black Sea, which are more reliable due to the DA techniques considered. In this way the present database covers a 15-year period (1999-2013), with 3 years more than the initial objective of the project. DA algorithms were implemented and the results obtained at various computational levels of the wave prediction system were validated. The original results regarding the implementation of the DA methodologies in the Black Sea basin were disseminated at various international conferences or papers published in ISI or BDI journals. The databases created in the framework of this project were also used for various studies in related fields as renewable energy (wave/wind), coastal protection and offshore operations.

References

Janssen, P.A.E.M., 1991. Quasi-linear theory of wind-wave generation applied to wave forecasting. *J. Phys. Oceanogr*. 21, 1631–1642.

Răileanu, A., Rusu, L., Rusu, E., 2015. Wave modelling with data assimilation in the Romanian nearshore. In: Proc. of 16th International Congress of the International Maritime Association of the Mediterranean, IMAM 2015 - Towards Green Marine Technology and Transport, 21-24 September, Croatia, pp. 837-843.

Răileanu, A., Rusu, E., 2015. Evaluation of Various Data Assimilation Procedures to Increase the Reliability of the Wave Predictions in the Black Sea, Oral presentation at the Scientific Conference organized by the Doctoral Schools of "Dunarea de Jos" University of Galati (CSSD-UDJG 2015), 4-5 June, Galati, Romania.

Rusu, E., Butunoiu, D., 2015. Prediction of the extreme storms in the Black Sea with numerical wave models, In:*Proc. of 16th International Congress of the International Maritime Association of the Mediterranean*, IMAM 2015 - Towards Green Marine Technology and Transport, 21-24 September, Croatia, pp. 845-851.

Rusu, L., 2014. A data assimilation scheme to improve the wave predictions in the western side of the Black Sea. In: *Proc. of 14th International Multidisciplinary Scientific GeoConference* (SGEM2014) – Marine and Ocean Ecosystems, 17-26 June, Albena, Bulgaria, Vol. II, 539-545.

Rusu, L., 2015a. Assessment of the Wave Energy in the Black Sea based on a 15-Year Hindcast with Data Assimilation. *Energies*, 8 (9), 10370-10388.

Rusu, L., 2015b. Wave modelling with data assimilation to evaluate the wave energy patterns in the Black Sea. In: *Proc. of 15th International Multidisciplinary Scientific GeoConference* (SGEM2015), 16-25 June, Albena, Bulgaria, Vol. 4, pp. 597-606.

Van der Westhuysen, A.J., Zijlema, M., Battjes, J.A., 2007. Nonlinear saturation- based whitecapping dissipation in SWAN for deep and shallow water. *Coastal Eng*. 54, 151–170.

Budget 2015: 210.571 lei

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